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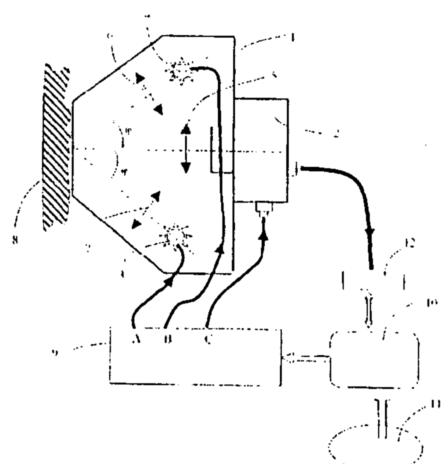
(54) PHOTOGRAPHIC DEVICE FOR NON-CONTACT MEASUREMENT AND 3-D REPRESENTATION OF THE CUTANEOUS MICRO RELIEF

(57) Procedure and device permitting the performance of a measurement of the roughness or micro relief of a surface 8, in particular of the skin of a living subject, characterized by the fact that it includes, in combination, two light sources 3 and 4 suitably arranged on either side of the median plane of the surface to be studied and each emitting a beam directed towards the said surface, a photo sensor 2 arranged between the two light sources and intended to capture, preferably in digital form, the images of the surface to be studied illuminated alternately by one or the other source of light. Two images of the surface to be studied are thus obtained from the same viewpoint but with two different incidences of illumination so that for each point on the surface there correspond two image elements the combination of which, using an algorithm 11, permits the calculation of the slope of the relief of the said point. The relief is then obtained by integration over all the points of the surface of the slopes at each of the said points.



FR 2 821 152 - A1

PHOTOGRAPHIC DEVICE FOR NON-CONTACT MEASUREMENT AND 3-D REPRESENTATION OF THE CUTANEOUS MICRO RELIEF

The present invention relates to a procedure and device having the purpose of measuring the cutaneous micro relief during the different phases of an anti-wrinkle treatment. The technical sector of the invention is the domain, but not solely, of the implementation of equipment for the evaluation of the anti-wrinkle treatments of the cosmetic industry.

The procedure and device of the present invention can be used in any application where a determination of the micro-relief or of the state of roughness of a surface are sought. However, to simplify the presentation of the prior art, mainly the references to applications in cosmetology will be cited below.

Carried out in parallel to the usual pharmacological tests, the measurement of the cutaneous micro relief during the various phases of an anti-wrinkle treatment is at present the only objective means of verifying its clinical efficacy. The cosmetic industry regularly tests its products on the natural scale by 3-D measurement of silicone impressions molded on the subjects of a test population. The comparative study of these results with those obtained on a reference population permits the statistical observation of the efficacy of the treatment applied.

At present, the high performance means of measurement at the disposal of researchers permit the analysis of the depth of the wrinkles with a resolution of from 5 to 50 microns. Excluding the mechanical means of standard metrology, the available optical methods are based on one of the following two principles:

- Triangulation: The geometric treatment of information delivered by two crossed sensors provides the 3-D coordinates of the points observed. This principle is typically that of photogrammetry: nevertheless, the absence of points that can be marked on the skin leads the constructors to use mobile optical marking (slits or laser plane) the displacement of which slows down the acquisition of the measurements.

- Depth of field: The sample is observed point by point by means of a microscope system. At each point, the displacement of the autofocus lens is correlated to the observation distance. This method is extremely precise but requires several minutes to scan the entire sample with a pitch sufficient for the study.

These two principles do not offer the speed indispensable to the instant acquisition of the measurements, and they are only applicable to inert samples. Cutaneous molding remains mandatory in all cases.

The elimination of molding (and sometimes of the countermolding) would allow reduction of the cost per subject of a test campaign, and consequently the testing of a broader population.

A solution to the problems posed above is a procedure for the measurement of the cutaneous micro-relief by a means permitting rapid and direct acquisition on the subject.

According to the process that is the subject of the invention, the study of the cutaneous micro-relief is obtained by a specific analysis of which the principle is described below, of two video images taken with a single photographic apparatus. The said images represent two photographs of the surface to be analyzed having the same point of view with two different illuminations activated sequentially, the whole process being effectuated in less than 0.1 seconds. The photo apparatus used is preferably of the CCD sensor type so as to obtain digitized images. The two sources of lighting are arranged according to two angles of 30 degrees for example on either side of a plane perpendicular to the surface to be studied. The skeleton diagram of the process in accordance with the invention is given in plate 1. To make the importance of the process in accordance with the invention better understood, in that it permits the calculation and rapid measurement of a micro relief using a single sensor, it is appropriate to state the theoretical bases that were used to conceive and implement the device in accordance with the invention.

Analytical Method

It is considered that the luminance of a surface element is defined by a function linking the angle of incidence of the illumination, the position of the sensor relative to the source, and the reflective power of the sample. Knowing these parameters, constant for the whole photograph, it is possible to determine by its gray level the angle made by a surface relative to the incident light, taken as the reference direction. The consideration of two incidences, clearly different by 60 degrees for example, permits the analysis of samples that are not homogeneous on the chromatic level.

The studies carried out, particularly by metallurgists, on the roughness of a surface illuminated in accordance with a known incidence by image treatment have shown that the gray level at a point does not depend on the height but on the slope of the profile at this point. The slope of the roughnesses is thus an affine function of

the microtopography of the surface analyzed. This determination remains valid as long as the photo sensor and the light source are sufficiently distant relative to the height of the profiles.

It is thus considered that the luminance of a surface element is defined by a function linking the angle of incidence of the illumination and the position of the sensor in relation to the source. Knowing these parameters, constant for the entire photograph, it is possible to determine by its gray level the angle made by a surface relative to the incident light, taken as the reference direction.

This treatment delivers for every image element the local slope of the corresponding surface element. The integration of the slopes given by the adjacent image elements permits, by propagation from an altimetric reference, the determination of the depth at each point of the image.

In order to find a relation linking the angle of incidence of illumination and the position of the sensor, we relied on the Phong model of which a detailed description will be found in the work: Image Synthesis, by Bernard Peroche, Jackeline Argence, Djamchid Ghazanfarpour and Dominique Michelucci, published by Hermes.

The lighting or illumination describes the intensity of the light reflected by an image element on the surface of the object and seen by the user. The "Phong illumination model" was developed by Bui-Tuong-Phong; it is illustrated in Figure 1.

We consider that the light source is a point. The surface of the object is illuminated by direct light coming from the source which is reflected in accordance with the vector R which makes an angle θ with the normal N to the surface. At the same time, the object is illuminated by the ambient light which will be partly reflected towards the observer. The position of the latter relative to the surface of the object is localized by the vector V. The intensity I of the light of wavelength λ perceived by the observer is given by equation 1:

Equation 1:

$$\boxed{I_\lambda = I_{a\lambda} K_a O_{d\lambda} + f_{att} I_{p\lambda} [K_d O_{d\lambda \cos}\theta + K_s O_{s\lambda} \cos^n a]}$$

with $I_{a\lambda}$ = intensity of the ambient light

$I_{p\lambda}$ = intensity of the point source of light of wavelength λ

K_a = coefficient of reflection of the ambient light by the surface

K_d = coefficient of reflection for the diffusion

K_s = coefficient of specular reflection

$O_{d\lambda}$ = diffusion color of the object

$O_{s\lambda}$ = specular color

f_{att} = atmospheric attenuation factor

This equation is perfectly suited to our practical applications since it involves the desired coefficients. Experimentally, we will work under different conditions and because of this the equation will be simplified by the elimination of certain coefficients:

- all the applications will be accomplished in a room isolated from all exterior light (no ambient light, therefore $I_{a\lambda}$, K_a, $O_d = 0$)
- the atmospheric attenuation factor will be equal to 1 because we will be working over short distances
- we will not take into account the diffusion color and the specular color because our surface will be white and it will be illuminated by white light.

On the other hand, the specular reflection models the light reflected by a bright surface such as a mirror or an automobile body. In this case, there is a zone close to the normal N where the color of the object appears "white." The reflected light is especially intense when the angle α delimited by R and V is small. The reflected light component drops rapidly when α increases. In the Phong model, a function $\cos^n\alpha$ is used to represent this. The larger it is, the more $\cos^n\alpha$ decreases rapidly and the specular reflection quickly reaches zero.

The surfaces that we will study will be matte, so that its characteristics resemble those of the skin. Under these conditions, n is the smallest possible whole number, that is, n=1.

After the modifications introduced, we obtain a more simplified form of the above equation:

Equation 2:

$$\boxed{I_\lambda = I_{p\lambda}\,(K_d\cos\theta + K_s\cos\alpha)}$$

The above function will be applied for the luminous intensity coming from the left-hand illumination and for the luminous intensity coming from the right-hand illumination. We note that this function is not bijective over a defined interval. This is why we make the difference in the two intensities so as to obtain a bijective function,

that is, one that is strictly monotone over a defined interval. By means of the luminous intensity, we will be able to determine the angle of incidence. We will fix [it] as the difference $I_{\lambda G} - I_{\lambda D}$.

Principal set-up diagrams

In our case, we can observe that the camera apparatus acts as the observer. The first diagram, Fig. 2, represents the experiment when the right-hand illumination is lit.

The Phong formula brings in two angles θ and α. θ is the angle formed by the incident ray with the normal to the surface and α is the angle formed by the observer (camera position) with the reflected ray. These two angles cannot be known, which is why we involve two other angles ϕ and β. ϕ is the angle formed by the incident ray with the observer and β is the angle formed by the surface with the axis of the abscissa. This is the angle of inclination of the surface. The angle ϕ will remain constant throughout the experiments.

<u>Determination of the Phong equation with parameters β and ϕ</u>

Taking equation 2, for the left-hand illumination:

$$I_{\lambda G} = I_{p\lambda}\,(K_d\cos\theta_1 + K_s\cos\alpha_1)$$

Putting $\theta_1 = \phi + \beta$

Putting $\alpha_1 = \theta_1 + \beta$, thus $\alpha_1 = \phi + 2\beta$

The above terms are then replaced in the equation to give:

$$\boxed{I_{\lambda G} = I_{p\lambda}\,[K_d\cos(\phi + \beta) + K_s\cos(\phi + 2\,\beta)]}$$

Taking equation 2, for the right-hand illumination:

$I_{\lambda D} = I_{p\lambda}\ (K_d \cos\ \theta_2 + K_s \cos\alpha_2)$

Putting $\theta_2\ = \phi + \beta$

Putting $\alpha_2 = \beta - \theta_2$, thus $\alpha_2 = 2\beta - \phi$ [sic]

The above terms are then replaced in the equation to give:

$$\boxed{I_{\lambda D} = I_{p\lambda}\ [K_d \cos(\phi - \beta) - K_s \cos(2\ \beta - \phi)]}$$

Then, proceeding to the difference between the two intensities:

$$I_{\lambda G} - I_{\lambda D} = I_{p\lambda}\ [K_d \cos(\phi + \beta) + K_s \cos(\phi + 2\beta)] - I_{p\lambda}\ [K_d \cos(\phi - \beta) + K_s \cos(2\ \beta - \phi)]$$

$$I_{\lambda G} - I_{\lambda D} = I_{p\lambda}\ [K_d \cos(\phi + \beta) - \cos(\phi - \beta)) + K_s(\cos(\phi + 2\ \beta) - \cos(2\ \beta - \phi))]$$

On one hand we have:

$$\cos(\phi + \beta) - \cos(\phi - \beta) = \cos(\phi)\cos(\beta) - \sin(\phi)\sin(\beta)-\sin(\phi)\sin\beta - \cos\ (\phi)\cos(\beta)-\sin(\phi)\sin(\beta)$$

$$\boxed{\cos(\phi + \beta) - \cos(\phi - \beta) = -2\ \sin(\phi)\sin(\beta)}$$

On the other hand we have:

$$\cos(\phi + 2\beta) - \cos(2\beta-\phi) = \cos(\phi)\cos(2\beta) - \sin(\phi)\sin(2\beta)- \cos(2\beta)\cos(\phi)-\sin(2\beta)\sin(\phi)$$

$$\boxed{\cos(\phi +2\ \beta) - \cos(2\beta - \phi) = -2\ \sin(\phi)\sin(2\beta)}$$

Finally, we arrive at the final formula given by equation 3, following:

$$I_{\lambda G} - I_{\lambda D} = I_{p\lambda}\ [K_d(\cos(\phi + \beta) - \cos(\phi - \beta)) - K_s \cos(\phi + 2\beta) - \cos(2\beta - \phi))]$$

$$I_{\lambda G} - I_{\lambda D} = I_{p\lambda}\ [K_d(-2\sin(\phi)\sin(\beta)) + K_s(-2\sin(\phi)\sin(2\beta))]$$

Equation 3:

$$\boxed{I_{\lambda G} - I_{\lambda D} = 2I_{p\lambda}\ [K_d \sin(\phi)\sin(\beta) - K_s \sin(\phi)\sin(2\beta)]}$$

Equation 3, which expresses the difference between "left-hand" and "right-hand" luminances as a function of β (ϕ, Kd Ks being constants) thus permits us to know the slope at every point or image element of the surface and thus by integration to plot the profile except for a multiplicative and additive coefficient. The said coefficients are to be determined by calibration measurements.

In one of the methods of implementation of the device in accordance with the invention, shown in a diagram in Fig. 4, in a housing 1 can preferably be grouped the photo sensor 2 which can be movable and the two light sources 3 and 4 which will be fixed. The convergent lenses 6 and 7 are arranged on the trajectory of the luminous fluxes and direct the said fluxes so that they converge on the surface 8 to be studied, and represented here in section. The reflected light, captured by the apparatus 2, is focused by the lens 5. The optical axes of the lenses 5, 6, 7 which are drawn in one plane thus converge on the surface 8 and form between them a constant angle ϕ. The implementation of the process in accordance with the invention requires a computer 10, for example of the PC type. The said PC controls the sequences of lighting of 3 and 4, of triggering of the sensor 2 and of acquisition of the digital images via the interfaces 9 and 12 as in the diagrams in Fig. 5. The electronic interface 9 includes devices (commutators) well known to electronics engineers, connected to the terminals A, B and C, which permit the closing, respectively, of the circuits for the supply or actuation of 2, 3 and 4. The electronic interface 12 is a converter permitting digitalization of the image signals coming from the sensor 2. In a procedure for measuring the cutaneous relief, for example, the acquisition sequence unwinds as in the chronogram in Figure 5: A is conductive (source 3 is lit), after a brief delay τ, C is conductive (first photograph is taken), A is shut off and B is conductive, after a short delay τ, C is conductive (2nd photograph is taken). The acquisition time does not exceed 0.1 seconds all together. The control and treatment of the process is assured by the specially designed "TOPOSKIN" software 11.

Claims

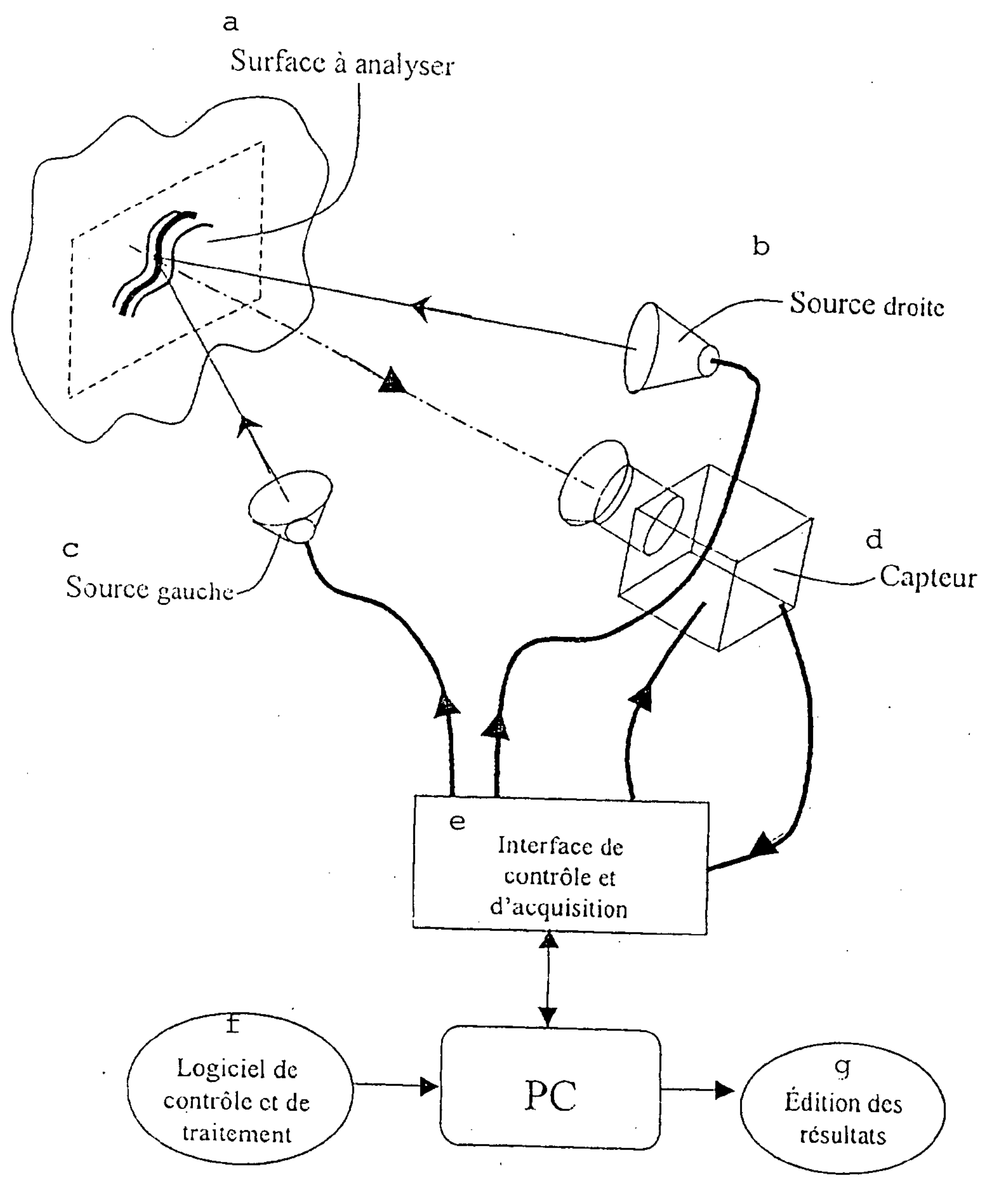
1. Device for measuring the roughness of a surface (8), including means (3,4) for illumination <7/8> of the surface (8), and sensor means (2) <7/7, 11> for the detection of an image in light reflected <7/11> by the surface (8), characterized by the fact that the means of illumination (3, 4) are actuated to illuminate the surface (8) in two defined directions <5/2,3> alternately <7/22-24> under the control of activation sequencing means (9) <7/22-24>, and means of calculation (10,11) <7/14> are provided, linked to the sensor means (2), to determine for a plurality of image points <7/3> the difference <6/10> between two intensities of light reflected from the image point considered to be illuminated in the two respective directions, for determining a representative value of a relative local angle of slope in relation to a predetermined direction and to determine the roughness by composition of the representative values of the slopes of adjacent points <7/2>.

2. Device in accordance with claim 1, in which the sequencing means are controlled by the means of calculation (10, 11).

3. Device in accordance with one of the claims 1 and 2, including a case to protect against stray light, including a support window for the surface (8).

4. Process for the measurement of the roughness of a surface (8), in which the surface (8) is illuminated by a luminous source and an image is detected by means of a reflected light sensor, characterized by the fact that the surface (8) is illuminated in two defined directions alternately, the image detected is supplied to calculating means (10, 11) which determine, for each of a plurality of image points, a difference between two intensities of light reflected from the image point considered illuminated in the two respective directions, which determine from this a representative value of a relative local angle of slope in relation to a predetermined direction and which determines the roughness by composition of the representative values of the slopes of adjacent points.

5. Process in accordance with claim 4, in which a preliminary standardization <7/5> of the means of calculation (10, 11) is effectuated so that the representative value provides the absolute value of the slope.



Key to Diagram above:

a = Surface to be analyzed

b = Right-hand source

c = Left-hand source

d = Sensor

e = Control and acquisition interface

f = Control and treatment software

g = Formatting of results

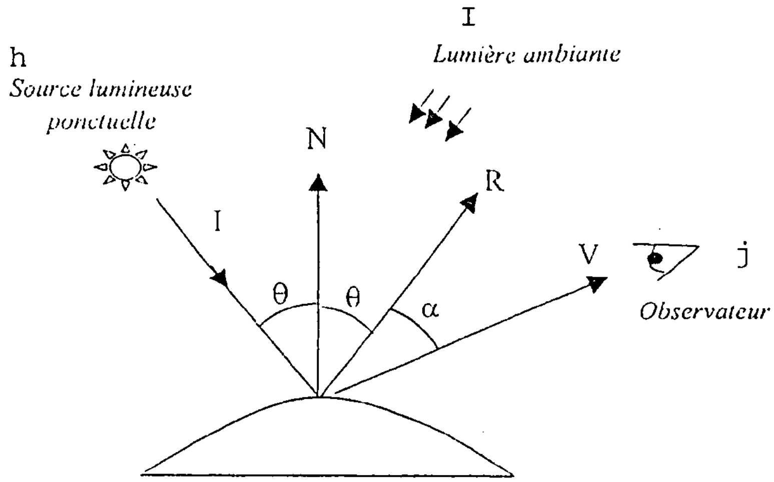


FIG.1

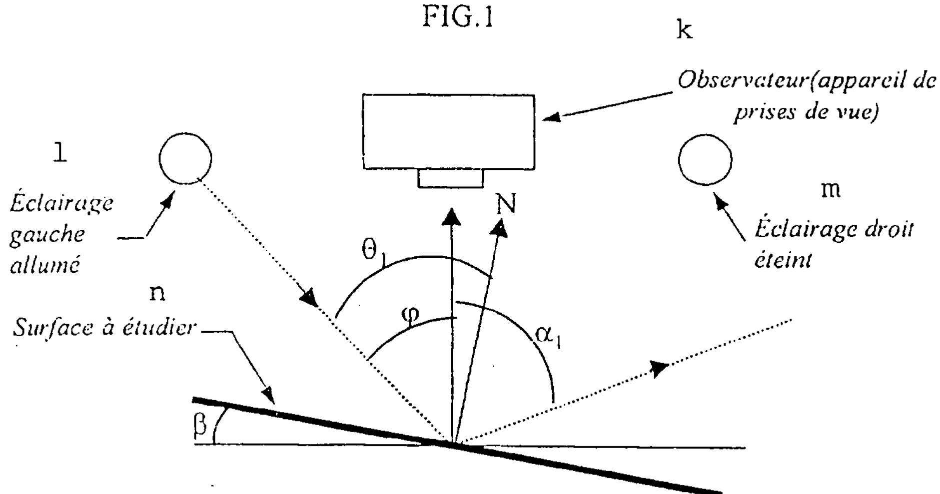


FIG.2

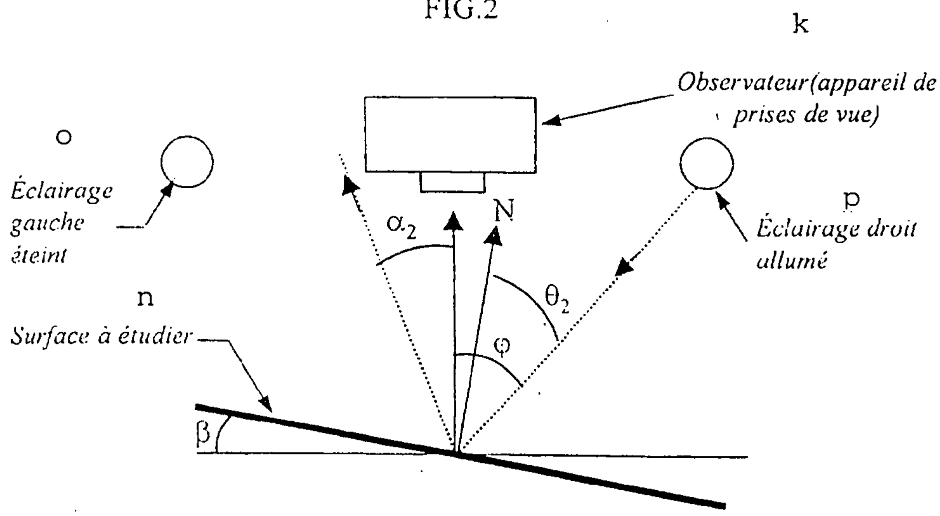


Fig. 3

Key to Diagram 1	Key to Diagram 2	Key to Diagram 3
h = Point light source I = Ambient light j = Observer	k = Observer (camera apparatus) l = Left-hand illumination, lit m = Right-hand illumination, not lit	n = Surface to be studied o = Left-hand illumination, not lit p = Right-hand illumination, lit

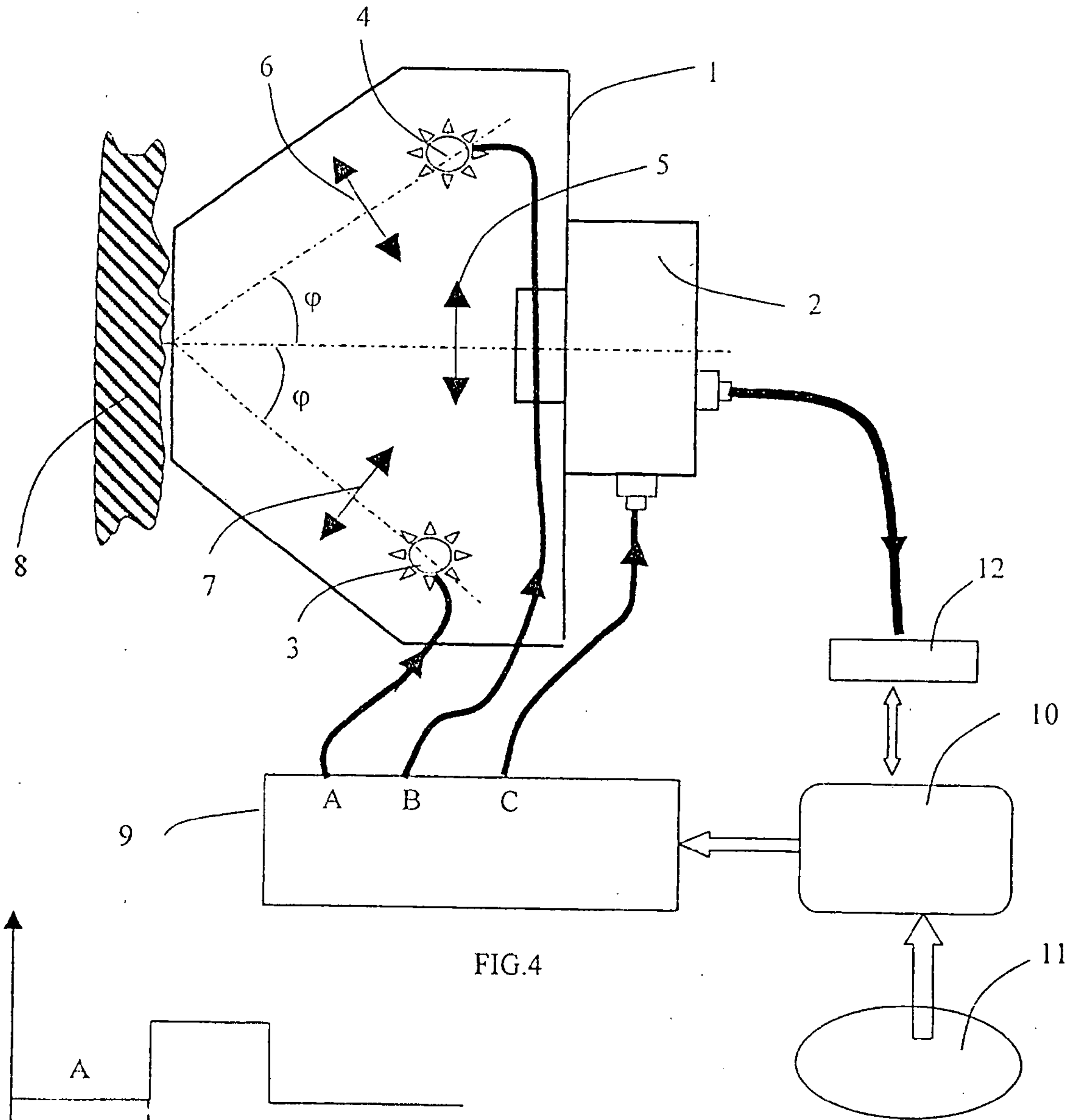


FIG.4

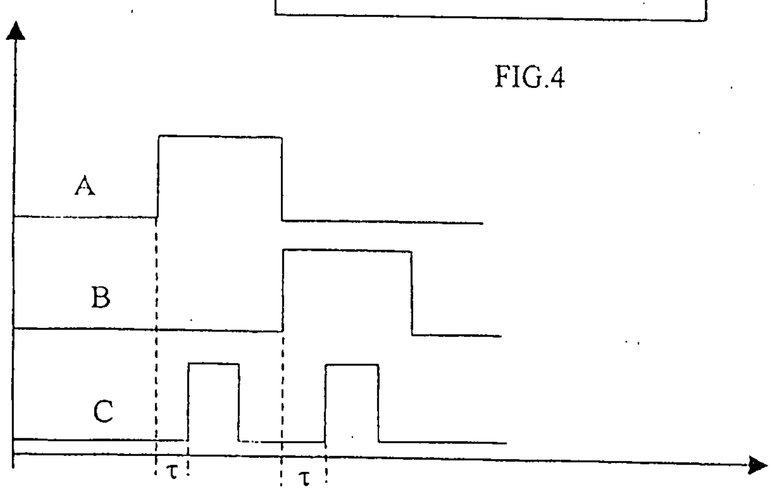


FIG.5